論文の内容の要旨

A Novel Efficient Method for Total Transfer Capability Evaluation of a Power System Integrated with Renewable Energy

(再生可能エネルギーを大量導入した電力系統における
効率的な送電可能容量算出手法に関する研究)

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Abstract

Security management of a transmission network has always been one of the challenging tasks for system operators especially within a competitive environment where a transmission network is commonly operated close to its limits. With this regard, Total Transfer Capability (TTC) was introduced by NERC in 1996 to be used as an index which measures the ability of a transmission network to carry or move electric power from one location to another across the system. It also represents one of the system operational limits, useful information for system operators in managing the security of a transmission network. There are several issues to be considered when evaluating the TTC, i.e. the uncertainty associated with the system parameters and conditions, voltage and transient stability constraints.

Over the last few years, it can be witnessed a rapid renewable energy development throughout the world mainly as a result of rising environmental concerns. Renewable energy is expected to be a clean and sustainable energy source for future electricity production. Japanese government already set out a target of 6610 MW wind power and 53 GW photovoltaic (PV) by 2030. However, a large penetration of renewable energy may pose an undesirable impact on the system security and reliability. Unlike conventional energy sources, renewable energy sources have very limited dispatchability and intermittent power output fluctuating with the wind speed or climate. In the past, the impact of the uncertainty associated with the renewable energy was minor and often neglected. Nonetheless, as more and more renewable energy is penetrating into a power system, the impact becomes significant and cannot be simply overlooked.

Another technical issue for the TTC evaluation is the integration of the voltage and transient stability constraints. From the system security viewpoint, the voltage stability should be ensured by operating a system with a sufficient margin away from the voltage collapse point. In many power systems, the transfer is sometimes restricted by the transient stability constraint following large disturbances. Some studies include the transient stability constraint into the TTC evaluation using Transient Stability Constrained Optimal Power Flow (TSCOPF), or energy function methods. Nonetheless, most of these studies have some limitations, and there is currently no investigation on a system integrated with renewable energy.

Therefore, this requires a new methodology which can properly take into account the uncertainty of the renewable energy power output and transient and voltage stabilities in order to ensure the system security. The objective of this dissertation is to develop a comprehensive scheme for the TTC evaluation by means of the probabilistic method suitable to address all of the above mentioned issues. Hence, one of the main contributions of this research is to fulfill the need and provide system operators and engineers with a suitable analytical tool. The developed method employs Monte Carlo simulation which is justified over other probabilistic methods due to its flexibility in handling and incorporating the uncertainty associated with various kinds of parameters. The TTC is selected based on the risk concept in which the stochastic nature of a system and fault is fully reflected. Voltage stability is ensured by specifying a sufficient margin away from the voltage collapse point, giving a system a room for unexpected incidences. Transient stability is assessed by the time-domain simulation where the detailed models of a synchronous generator together with its controllers, e.g. an exciter and turbine governor, wind power and PV systems can be included. By using the proposed TTC evaluation method, several interesting points regarding the impact of the uncertainty, penetration level of renewable energy, voltage and transient stabilities on the TTC are investigated and discussed.

In addition to the development of the TTC evaluation method, this dissertation proposes a novel efficient method for the TTC evaluation. As is known, the main disadvantage of the Monte Carlo method is its high computation cost as it usually requires a sufficiently large sample size for its convergence. Hence, this time-consuming process is the main impediment to its widespread use for the TTC evaluation. Moreover, the addition of voltage and transient stability assessment results in an extensive computation burden. To overcome such drawbacks, this dissertation proposes several techniques to help speed up the computation, i.e. voltage stability index, system case partitioning using two filters, and decision tree classification.

Commonly used to estimate the proximity away from the voltage collapse point, a voltage stability index is employed in the TTC evaluation to screen out the cases within the Monte Carlo sample set, which are prone to have an insufficient voltage stability margin. With a proper selection of a threshold, a significant number of cases to be checked during Monte Carlo simulation can be reduced. Furthermore, the run time can be saved by reducing the number of cases to be evaluated during Monte Carlo simulation. This is accomplished by system case partitioning. Generally, the system cases in the Monte Carlo sample set can be classified into non-risk-related and risk-related cases respectively, where only the latter are needed to obtain the risk-based TTC value. The system case partitioning uses two filters to grasp the risk-related cases from the Monte Carlo sample set. The first filter is based on the performance indices which are used to measure the severity degree of the system condition and based on which the cases are ranked. The second filter employs a decision tree with one input attribute to roughly screen out the cases prone to transient instability. The results from the two filters are later used to build the partitioned set. Besides, another decision tree with more input attributes is used for fast transient stability prediction. Instead of a time-consuming time-domain simulation, the system stability can be quickly assessed by the decision tree based on the classification patterns it learns from the training data. The performances of the proposed efficient TTC evaluation method in terms of both accuracy and computational speed enhancement are validated and examined via the numerical simulation. The simulation results show that the proposed efficient TTC evaluation method can significantly reduce the run time from the original of 4373 sec to 1255 sec, i.e. saving as much as 71%, while still obtaining an accurate TTC with the error less than 1%.

Finally, the impact of Low Voltage Ride-Through (LVRT) on the transient stability and TTC has also been studied. A generating unit which cannot ride through the excursion of the voltage during the fault is disconnected mainly to protect its equipment from possible damages due to a high fault current, especially power electronics (i.e. an inverter of a PV system). Disconnection of a generating unit is found to affect the system stability; however, depending on several factors. Some faults which cause a drastic drop in the voltage and lead to the disconnection of large generating units, may have a very severe impact on the system stability and frequency stability as the system needs to find generation to make up with the portion lost. This can further lead to a cascading failure phenomenon; hence, an undesirable large-scale power interruption. However, such severe faults may not occur frequently or do not occur at all within the specified lead-time; hence, the impact on the TTC may not be so apparent.

In the future, transfer capability evaluation is still expected to be one of the challenging and important tasks for the system operators as it has always been to maintain the system security and, at the same time, achieve efficient operation. New problems are also expected as a power system evolves with the introduction of new constraints and emerging advanced technologies, renewable energy and communication technologies. The proposed method together with the research findings presented in this dissertation provides key useful information on the TTC which can be later used for achieving efficient operation and planning of a power system. In addition, the proposed TTC evaluation scheme and several speed enhancement techniques can serve as a basis and efficient analytical tool for the future research and development.